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A review of biodiesel as vehicular fuel

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Abstract

This article is a literature review of use of biodiesel fuel for compression ignition engines. This study is based on the reports of about 50 scientists including (some manufacturers and agencies) who published their results between 1900 and 2005. The scientists and researchers conducted the test, using different types of raw and refined oils. These experiments with raw biodiesel as fuel did not show the satisfactory results, when they used the raw biodiesel. The fuel showed injector coking and piston ring sticking.

Some of the scientists mixed with methanol or ethanol in presence of KOH or NaOH and then filtered and washed. The process is called transeterfication and is used to degum, dewax and to remove triglycerides from the vegetable oils. Transeterfication decreases the viscosity, density and flash point of the fuel. The results obtained, by using such oils in compression ignition engines as fuel, were satisfactory only for short term.

A vast majority of scientists mixed the transesterified biodiesel oil with diesel with different ratios. When tested in long run, blends of the oil above 20% (B20) caused maintenance problems and even sometimes damaged the engine. Some authors reported success in using vegetable oils as diesel fuel extenders in blends of more than 20% even in long-term studies.

The main conclusion derived by the researchers is that coking is a potentially serious problem with the use of unmodified vegetable biodiesel. However, the refined, chemically processed and degumed vegetable oil mixed with diesel can be used to run compression ignition engine for longer duration.

It was reported that there was a slight decrease in brake power and a slight increase in fuel consumption. However, the lubricant properties of the biodiesel are better than diesel, which can help to increase the engine life. Moreover, the biodiesel fuel is environment friendly, produces much less NO_x and HC and absolutely no So_x and no increase in CO_2 at global level.

Keywords: Vegetable oils; Biodiesel; C I engine; Exhaust emission

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Contents

1. Introduction

The petroleum fuel is a blessing of God. It plays a vital role in industrial development, transportation, agriculture sector and to meet many other basic human needs. However, the world energy demand is increasing rapidly due to excessive use of the fuels but because of limited reservoirs, the researchers are looking for alternative fuels. Another serious problem associated with the use of petroleum fuel is the increase in pollutants emissions. For instance, tons of the diesel are burnt in Lahore daily which leads to increase in CO_2, HC, NO_x, SO_x and many other nasty gasses. These polluted gasses are badly affecting the respiratory system, the nervous system of people and producing a large number of skin diseases. These gases also damage the health of animals and affect the plants and trees. Acid rain is also due to these pollutants emission gasses. So the need to search alternative fuels is inescapable.

Biodiesel can be one of the best alternatives. It is made from the oils of various types of oilseed crops like sunflower, palm, cottonseed, rapeseed, soybean and peanut.

The use of biodiesel is almost as old as diesel engine itself. Rodulf Diesel patented his engine in 1892 and introduced the first diesel engine intended to run on vegetable oil. In 1900 he ran the engine on peanut oil for several hours successfully. In 1912, he predicted that in future the vegetable oil will be a fuel like diesel oil [1].

The duel fuel engines remained in use for long time. In 1940, huge reservoirs of petroleum were found, its extraction and refinement was easy and cheaper. In 1970s, the monopoly of some nations and political circumstances developed a new situation, which forced the engineers and researchers to have an alternative and environment friendly

fuel. Since then there has been a renewed interest in using vegetable oils in diesel engines for various reasons including political considerations, environmental concerns and economic aspects.

The seed oil is filtered and treated chemically to reduce the viscosity and to improve the combustion and flow properties. Then it can be used as pure vegetable oil (B100) or by mixing it with diesel in any proportions. The results obtained by using a blend of diesel and vegetable oil, in an engine with a ratio of 80:20 (B20) were found to be the best. The biodiesel has a number of advantages over the diesel. It is a renewable, non-toxic and biodegradable. Since the biodiesel fuel (vegetable oils processed with methanol or ethanol) is a renewable fuel, so it is non-toxic and does not increase the level of CO_2 at all in the atmosphere at global level. The exhaust emission of the fuel absolutely does not have SO_x, and considerably less amount of NO_x are produced.

The scientist tested a number of different raw and processed vegetable oils like sunflower oil, cotton oil, rapeseed oil, soybean oil, palm oil. In this paper, the results of some of the scientists/researchers are compared and summarized.

2. Sunflower

The viscosity of crude sunflower oil is much higher, about 15 times greater than that of diesel oil. However it becomes very close to diesel, when it is transesterfied. The viscosity of methyl ester—processed by using methanol—is 3.2, while that of diesel is 2.8. The density of methyl ester is just 4.5% higher than diesel. These properties become nearly the same when the sunflower oil is used in the form of B20—blend of 20% vegetable oil and 80% diesel.

2.1. *Use of raw sunflower*

Bruwer et al. [2] studied the use of sunflower seed oil as a renewable energy source. He ran the tractors with 100% sunflower oil instead of diesel fuel and reported that an 8% power loss occurred after 1000 h of operation. The power loss was corrected by replacing the fuel injectors and injector pump. After 1300 h of operation, the carbon deposits in the engine were reported to be equivalent to an engine fueled with 100% diesel except for the injector tips, which exhibited excessive carbon build-up.

Walt and Hugo (1981) examined the long-term effects of using sunflower oil as a diesel fuel replacement in direct and indirect injected diesel engines. Indirect injected diesel engines were run for over 2000 h using de-gummed, filtered sunflower oil with no adverse effects. The direct injected engines were not able to complete even 400 h of operation on the 20% sunflower oil, 80% diesel fuel mixture without a power loss. Further analysis of the direct injected engines showed that the power loss was due to severely coked injectors, carbon buildup in the combustion chamber, and stuck piston rings. Lubricating oil analysis also showed high piston, liner and bearing wear.

Tahir et al. [3] tested sunflower oil as a replacement for diesel fuel in agricultural tractors. Engine performance using the sunflower oil was found similar to that of diesel fuel, but due to relatively lower heating value of sunflower oil than diesel, more fuel was consumed and engine produced slightly less power when it was fueled with sunflower oil.

Bettis et al. [4] analyzed sunflower, safflower, and rapeseed oils. He reported that the vegetable oils were found to contain 94–95% of the energy content of diesel fuel, and to be

approximately 15 times as viscous. Short-term engine tests indicated that for the vegetable oils power output was nearly equivalent to that of diesel fuel, but long-term durability tests indicated severe problems due to carbonization of the combustion chamber.

Other research at International Harvest Company [5] was done using three blends of sunflower oil and diesel fuel. Results indicated that the sunflower oil caused premature engine failure due to carbon buildup. It was noted that cold weather operation caused fuel system malfunctions.

Fuls [6] reported similar findings for indirect and direct injection engines using B20. Fuls was of the view that injector coking was the problem with using sunflower oil in direct injected diesel engines.

German et al. [7] made an on-farm study using six John Deere and Case tractors by averaged 1300 h of operation. Carbon deposits on the internal engine components were greater for the tractors fueled with 50/50 sunflower oil/diesel than for those fueled with a 25/75 sunflower oil/diesel fuel blend. All the test engines had more carbon build-up than normally seen in an engine fueled with diesel fuel.

2.2. *Use of processed sunflower*

In 1983 Engler et al. [8] studied the engine performance using sunflower and cottonseed by substituting diesel. They reported that engine performance was very poor while using these oils instead of diesel. However the performance is slightly better when the refined and degummed oils were used. Carbon deposits and lubricating oil contamination problems were noted, indicating that these oils were acceptable only for short-term use.

Yarbrough et al. [9] made experiments using sunflower oils as diesel fuel replacements. They published their results that raw sunflower oils were found to be unsuitable fuels, while refined sunflower oil was found to be satisfactory. The processing of sunflower oils is required to degumm and dewax, even if the vegetable oils were blended with diesel fuel, to prevent the failure.

Biofuel industries in their report entitled 'Sunflower Biodiesel' sunflower oil is an environmentally friendly alternative fuel. It reduces significantly the harmful exhaust emissions. There is a reduction of 12.6% CO_2, 11% HC, 18% particulates and 15% air toxics [biofuel industries] [10].

3. Cottonseed oil

The cottonseed oil is abundantly produced in Pakistan. The properties of methyl ester are also very much similar to diesel, particularly, when it is used in the form of B20. The viscosity of cottonseed oil is 3.2 and density is 0.9. These properties are comparable to diesel. However the iodine value (IV) of the oil is higher than diesel, so the oil is relatively less stable and more susceptible to oxidation.

3.1. *Use of raw cottonseed oil*

Goering et al. [11] studied the characteristic properties of 11 vegetable oils to determine which oils would be best suited for use as an alternative fuel source. He reported that corn, rapeseed, sesame, cottonseed and soybean oils had the most favorable fuel properties.

International Harvester Company [12] reported that cottonseed oil and diesel fuel blends behaved like petroleum-based fuels in short-term performance and emissions tests. The experimental fuels performed reasonably well when standards of judgment were power, fuel consumption, emissions, etc. However, engine durability was an issue during extensive use of these fuel blends because of carbon deposits and fueling system problems.

3.2. Use of processed cottonseed oil

International Harvester Science and Technology Laboratory [12] also conducted tests using blends of processed cottonseed oil and diesel. The cottonseed oil was refined almost to food grade in order to remove the gummed material and to reduce viscosity, by using an inexpensive commercial treatment. The cottonseed oil was mixed with diesel in blends of: 30%, 50%, 65% and 80% cottonseed oil. The tests were conducted 4 times, 15 h, each time. The results with a 50% blend were most satisfactory. So, a 200 h endurance test was conducted with the blended fuel. After the endurance test the engine showed scoring on two of the cylinders, the corresponding pistons were also deeply scored with the surfaces torn. All the engines' top rings were heavily filled with a very hard carbonaceous deposit, which was obstructing the rings functions.

4. Rapeseed oil

The flash point of rapeseed oil is 220 °C, which is much higher than that of diesel. It makes the ignition relatively difficult, but the transportation and handling is much safer. The calorific value is 10–15% less in comparison to diesel, but because of higher density the volumetric content of heat value is nearly about the same as that of diesel.

4.1. Use of raw rapeseed oil

Schoedder [13], in Germany, used rapeseed oil as a diesel fuel with mixed results. Short-term engine tests indicated rapeseed oil had comparable energy outputs to diesel fuel. The tests showed that difficulties arose in engine operation after 100 h due to deposits on piston rings, valves, and injectors. He indicated that further investigations are required to prepare the fuel, which is suitable for continuous running of engine and suggest the required modifications in the engine.

Studies in New Zealand by Sims et al. [14] indicated that vegetable oils, particularly rapeseed oil, could be used as a replacement for diesel fuel. According to his results, the initial short-term engine tests showed that a 50% vegetable oil fuel blend had no adverse effects. While in long-term tests they encountered injector pump failure and cold starting problems were also noted. Carbon deposits on combustion chamber components were found to be approximately the same as that found in engines operated on 100% diesel fuel. They concluded that rapeseed oil had great potential as a fuel substitute, but that further testing was required.

Worgetter [15] tested rapeseed oil as an alternative fuel in a 43 kW tractor engine. The test was aborted at about 400 h due to unfavorable operating conditions. The use of rapeseed oil in the fuel resulted in heavy carbon deposits on the injector tips and pistons. Upon engine tear down, it was found that the heavy carbon deposits on the pistons were the cause of the noted power loss and not the fuel injectors.

Wagner and Peterson [16] used rapeseed oil as a diesel fuel extender to study the long-term effects of using vegetable oil as a fuel. They used a blend of 70% rapeseed oil and 30% diesel fuel successfully to operate a small single cylinder engine for 850 h; which showed the excellent results. He also reported that the use of pure sunflower oil caused severe piston ring gumming and catastrophic engine failure. However, no adverse operating conditions were observed for short-term performance tests.

4.2. Use of processed rapeseed oil

Wagner and Peterson [16] reported mixed results when using rapeseed oil as a substitute fuel. Attempts to heat the oil fuel mixture prior to combustion exhibited no measurable improvement in fuel injection. Severe engine damage was noted during short-term engine testing due to the use of rapeseed oil. A long-term test using a 70% rapeseed, diesel fuel blend was successful for 850 h with no apparent signs of wear, contamination of lubricating oil, or loss of power.

McDonnell et al. [17] studied the use of a semi-refined rapeseed oil as a diesel fuel extender. Test results indicated that the rapeseed oil could serve as a fuel extender at inclusion rates up to 25%. As a result of using rapeseed oil as a fuel, injector life was shortened due to carbon buildup. However, no signs of internal engine wear or lubricating oil contamination were reported.

The kinematics viscosity of rapeseed oil is much higher, which affects the flow properties and characteristics of spray. It also cause the coking of injector nozzle. The positive point of this alternative fuel is, reduced sulfur contents, hence the production of SO_x, ash and residual are very small.

The experimental results also showed that it will create problems, when used unprocessed. Moreover, it should always be used in blended form.

5. Soybean oil

The properties of soybean oil are also very close to diesel. Its density is 0.884 kg/l at 21 °C. The cetane number of soybean oil is 51–58, and calorific value is 35 MJ/kg and the cetane no. of methyl ester is 46–67 and calorific value is 32 MJ/kg, while the cetane number of diesel is 48–50 and calorific value is 38.3 MJ/kg. The flash point of the ester is higher than that of diesel, which requires higher compression ratio and modifications in fuel injector to ignite the fuel in a smooth pattern.

5.1. Use of raw soybean oil

Engelman et al. [18] used a mixture of soybean oil and diesel fuel blends in diesel engines with a ratio of 10–50%. They tested the engine for 50 h and reported that carbon build-up in the combustion chamber was very small. For the fuel blends studied, it was reported that vegetable oils could be used as a fuel source in low concentrations. The BSFC and power measurements for the fuel blends only differed slightly from pure diesel fuel. Fuel blends containing 60% or higher concentrations of vegetable oil caused the engine to sputter. Engine sputtering was attributed to fuel filter plugging. They concluded that waste soybean oil could be used as a diesel fuel extender with no engine modifications.

Caterpillar Tractor Co. (McCutchen, 1981) compared engine performance of direct injection and indirect injection engines when fueled with 30% soybean oil, 70% diesel fuel. The results showed that the engines having indirect injection, using blended fuel could be operated satisfactorily. The problems were observed in the engines working on the direct injection system; which were engine coking and sticking of piston rings.

5.2. Use of processed soybean oil

Barsic and Humke [19] used crude soybean oil, a 50:50 mixture of crude soybean oil and diesel, and degummed soybean oil in a direct injection engine for a short term of 25 h. They published their results which indicated engine's performance and emissions for diesel and vegetable oils resulted in lower thermal efficiency, lower NO_x, more carbon monoxide, more hydrocarbons and more particulates for the vegetable oil. The crude and degummed soybean oil resulted 6% and 1% lower thermal efficiency as compared to diesel. The coking of nozzles in both cases increased the emissions, with the crude soybean giving a greater increase in total emissions than the degummed oil.

Braun and Stephenson [20], in the Pennsylvania State University carried out short term tests on blends of degummed soybean oil, ethanol and diesel with the ratios of: 40:20:40, and 40:30:30. They tested the engine for 25 h on each blend. No irregularities in the injector spray pattern were observed.

The exhaust emission of methyl ester derived from soybean oil is neat, free from SO_x less, NO_x and CO.

6. Palm oil

The palm oil is very frequently used in Malaysia as B5 as a biodiesel fuel. The iodine value of the oil is slightly greater than that of pure diesel The IV influences the long-time stability of properties. The viscosity is 3.5–5 and specific gravity 0.86–0.9; which is acceptable. However it works very pleasantly when it is used in the blend form with diesel oil. Like many other vegetable oils, its flash point is also higher than diesel (110° C). The cetane number is 53–59 [waste vegetable oil] [21].

6.1. Use of raw palm oil

Sapaun et al. [22] reported that studies in Malaysia, with palm oil as diesel fuel substitute, exhibited encouraging results. Performance tests indicated that power outputs were nearly the same for palm oil, blends of palm oil and diesel fuel, and 100% diesel fuel. Short-term tests using palm oil fuels showed no signs of adverse combustion chamber wear, increase in carbon deposits, or lubricating oil contamination.

Mohamed M. EI-Awad et al. [23] performed experiments by using palm oil to replace diesel oil. They used a four cylinder, four stroke direct injection diesel engine. The results show that the engine brake power, torque and brake specific fuel consumption when using crude palm oil (CPO) and diesel oil mixture are comparable with those when using ordinary diesel fuel oil under various operating conditions. Under light load operation, the CPO–diesel mixture suffered a loss of fuel efficiency and increased CO emissions relative to the diesel system. In the high-speed range, the CPO mixtures showed comparable

performance to that of diesel fuel for exhaust-gas composition and temperature, particularly the 25% and 50% CPO mixtures.

6.2. Use of processed palm oil

Prateepchaikul and Apichato [24] made a comparison of refined palm oil and diesel oil in a small single cylinder in-direct injection diesel engine. They ran the engine more than 2000 h. They concluded that during the 1000 h of operation the specific fuel consumption of the engine fueled by refined palm oil was 15–20% higher and the black smoke density was not significantly different but wear in the compression rings of the engine, fueled by refined palm oil was significantly higher as compared to the use of pure diesel.

In general, like all other biodiesel fuels palm oil is also an excellent alternative fuel. It creates less environmental pollution.

7. Peanut oil

Rudolf Diesel (1900) used peanut oil to run the diesel engine. In 1911 he wrote "The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of countries which will use it."

7.1. Use of raw peanut oil

Deere and Company [19] studied the effects of mixing peanut oil and sunflower oil with diesel fuel in a single-cylinder engine. The vegetable oil blends were observed to increase the amount of carbon deposits on the combustion side of the injector tip when compared with 100% diesel fuel. They commented that the vegetable oil fuel blends have a lower heating value than that of diesel fuel. Fuel filter plugging was noted to be a problem when using crude vegetable oil as diesel fuel.

8. Miscellaneous/unknown

Seddon [25] used different vegetable oils in dual fuel mode in diesel engine with great success. He remarked that vegetable oils could be used as alternative fuels in compression ignition engine vehicles under normal operating conditions.

Over 30 different vegetable oils have been used to operate compression engines since the 1900s [26]. Initial engine performance suggested that the oil-based fuels have great potential as fuel substitutes. Extended operations indicated that carbonization of critical engine components resulted from the use of raw vegetable oil as a fuel can lead to premature engine failure. Blending vegetable oil with diesel fuel was found to be a method to reduce coking and extend engine life.

Bacon et al. [27] tested several vegetable oils as potential fuel sources. They reported that the initial engine performance tests using vegetable oils were found to be acceptable, while use of these oils caused carbon build up in the combustion chamber. Continuous running of a diesel engine at part-load and mid-speeds caused rapid carbon deposition rates on the injector tips. Short 2 h tests were used to visually compare the effects of using different vegetable oils in place of diesel fuel. The engine performance was found satisfactory and no irregularly was found.

Caterpillar [28] reported that vegetable oils mixed with diesel fuel in small amounts did not cause engine failure. Short-term research showed that blends using 50/50 were partly successful, but that 20% vegetable oil fuel blends showed very good result.

Ryan et al. [29] characterized injection and combustion properties of several vegetable oils. They told that the atomization and injection characteristics of vegetable oils were significantly different from those of diesel fuel due to the higher viscosity of the vegetable oils. Engine performance tests showed that power output slightly decreased when using vegetable oil fuel blends. Injector coking and lubricating oil contamination appeared to be a more dominate problem for oil-based fuels having higher viscosities.

Pestes and Stanislao [30] used a one to one blend of vegetable oil and diesel fuel to study piston ring deposits. Premature piston ring sticking and carbon build-up due to the use of the one to one fuel blend caused engine failure. The maximum carbon deposits were found on the face of the first piston ring. These investigators suggested that to reduce piston ring deposits a fuel additive or a fuel blend with less vegetable oil was needed.

Nag et al. [31] studied the use of various oils grown natively in India. Performance tests using fuel blends of 50–50 seed oil from the Indian Amulate plant and diesel fuel exhibited no loss of power. Knock free performance with no observable carbon deposits on the functional parts of the combustion chamber were also observed during these tests. Although this seed oil was not commercially available at the time of this study, it was hoped that it will be widely available in near future. However, they did not mention which oil they used.

9. Conclusions

(1) Although almost all types of vegetable oils can be used to replace the diesel oil, however the rapeseed oil and palm oil can be the most suitable oils which can be used as diesel fuel extender.
(2) Vegetable oils alone can be used only for small engines for a short-term period. For long-term use and for heavy/big engines, blend of diesel and vegetable oils is recommended.
(3) These vegetable oils should be used after proper filtration, deguming and dewaxing. Proper quantities of other chemicals, such as methanol should be added to deacidify and decrease the viscosity.
(4) While using vegetable oils in place of diesel oil, indirect fuel injection system is more successful as compared to direct injection.
(5) The engine should be started by using diesel alone. After warming up it should be shifted to vegetable oil blend.
(6) More care and regularity in maintenance and periodic services of the engine is required.
(7) Since the biodiesel generates much less polluted gases as compared to diesel it would be better to use B100 in the urban areas.

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